NAVSEA
WARFARE CENTERS
Carderock Division

Navy Characterization of Covetic Aluminum

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Report Documentation Page

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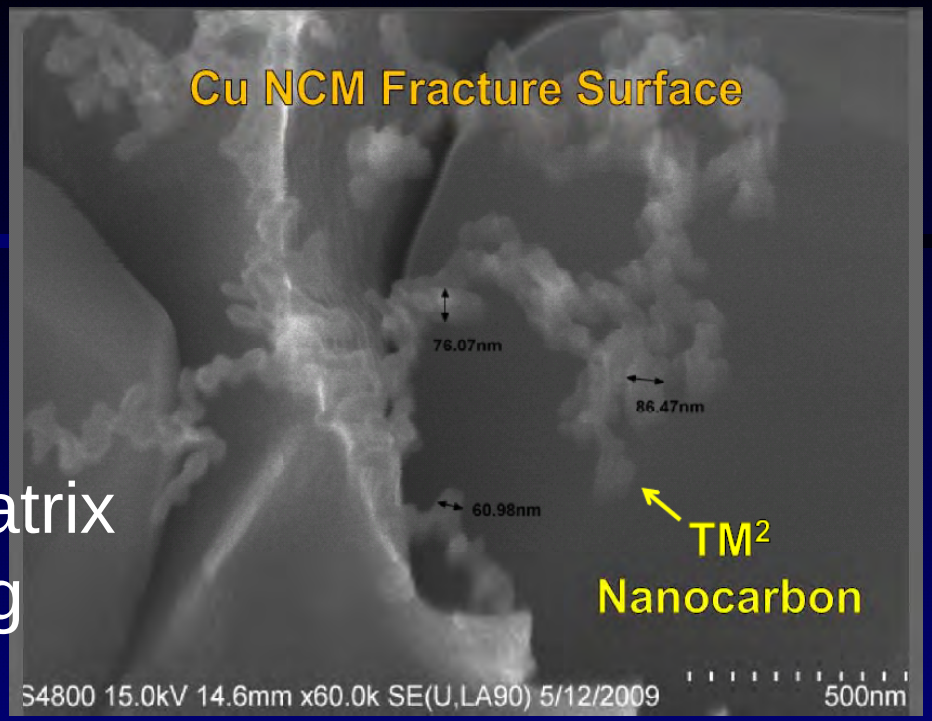
Summary

- There is a new class of materials: Covetic
  - Third Millennium Metals, LLC; 12-yr development
  - Nanoscale carbon phase, 3-10 wt. %
  - Chemically bound to metal in a way we still need to understand; probably a new nano-effect
  - Increased thermal conductivity, Al and Cu
- NSWCCD has verified some of the claims
  - Increased strength for same work hardening
  - Increased electrical conductivity in Al
- Possible lightweight aluminum armor—more testing needed

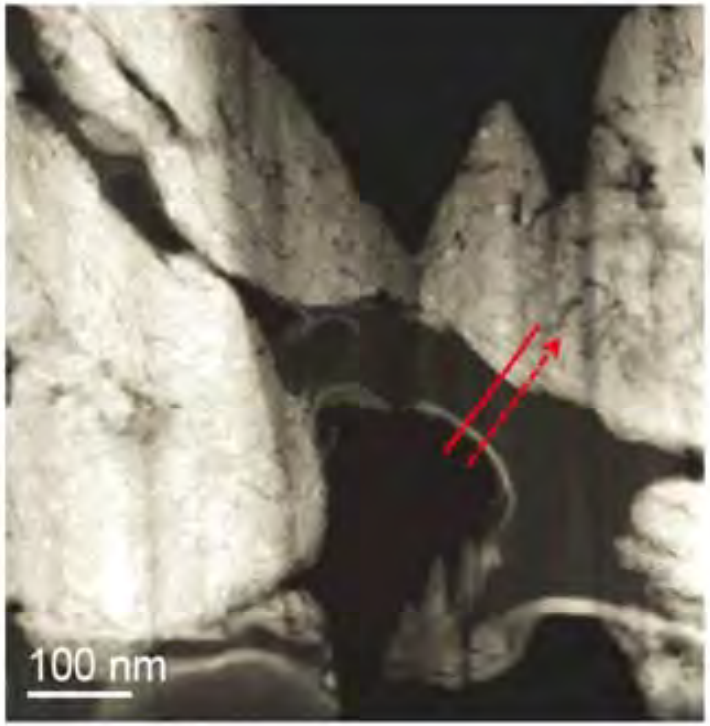
SEM

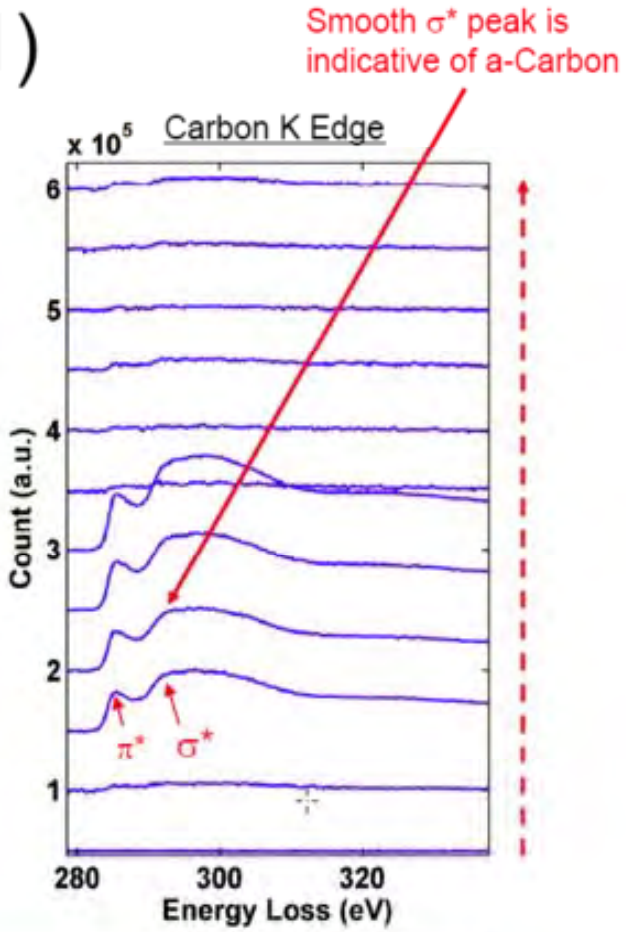


- In copper, we see
  - Approx. 50 nm particle chains
  - Chemically bound to metal matrix
  - Remains intact upon remelting
- In aluminum, we also see nanoscale carbon
  - But due to beam alignment issues we do not have good images yet

Electronic State of Carbon--Muller, Cornell

Big Void with Carbon Coated (ROI #1)





Voids between grains are coated with sp^2 amorphous carbon.

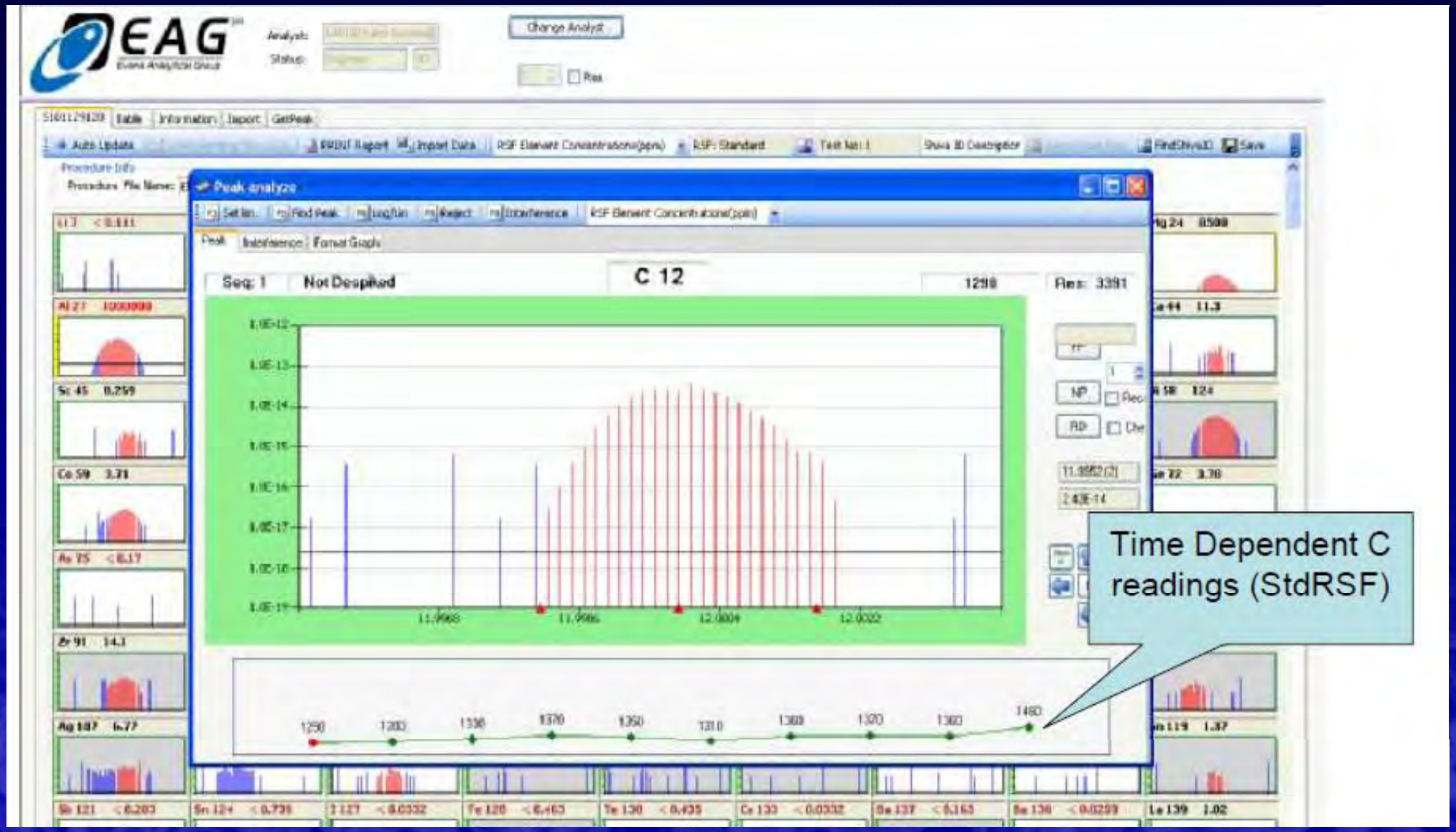
6061 Chemical Analysis (wt. %)

Carbon via LECO combustion method gives only 0.300% carbon inclusions.
The remaining 2.7% is NOT DETECTED.

	6061-0	H-49 Covetic	ASTM B211
C	0.003	0.300	0.05 max
Si	0.72	0.71	0.4 – 0.8
Fe	0.25	0.24	0.7 max
Cu	0.18	0.18	0.15 – 0.40
Mn	0.061	0.064	0.15 max
Mg	0.99	1.03	0.8 – 1.2
Cr	0.054	0.057	0.04 – 0.35
Zn	0.080	0.084	0.25 max
Ti	0.088	0.099	0.15 max
V	0.0072	0.0074	0.05 max

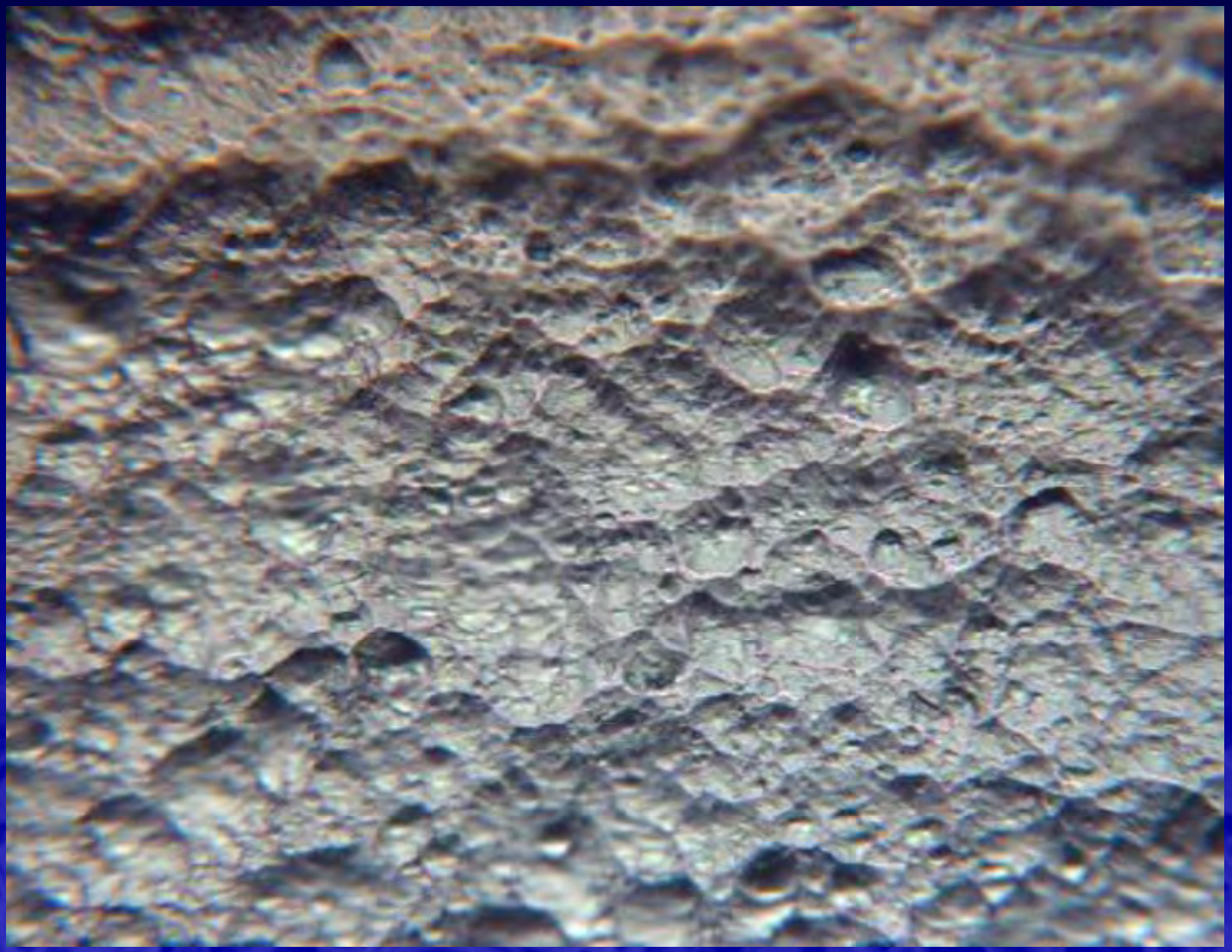
GDMS

Carbon via GDMS gives 0.22 wt%. However, measured level goes up over time during sputtering.



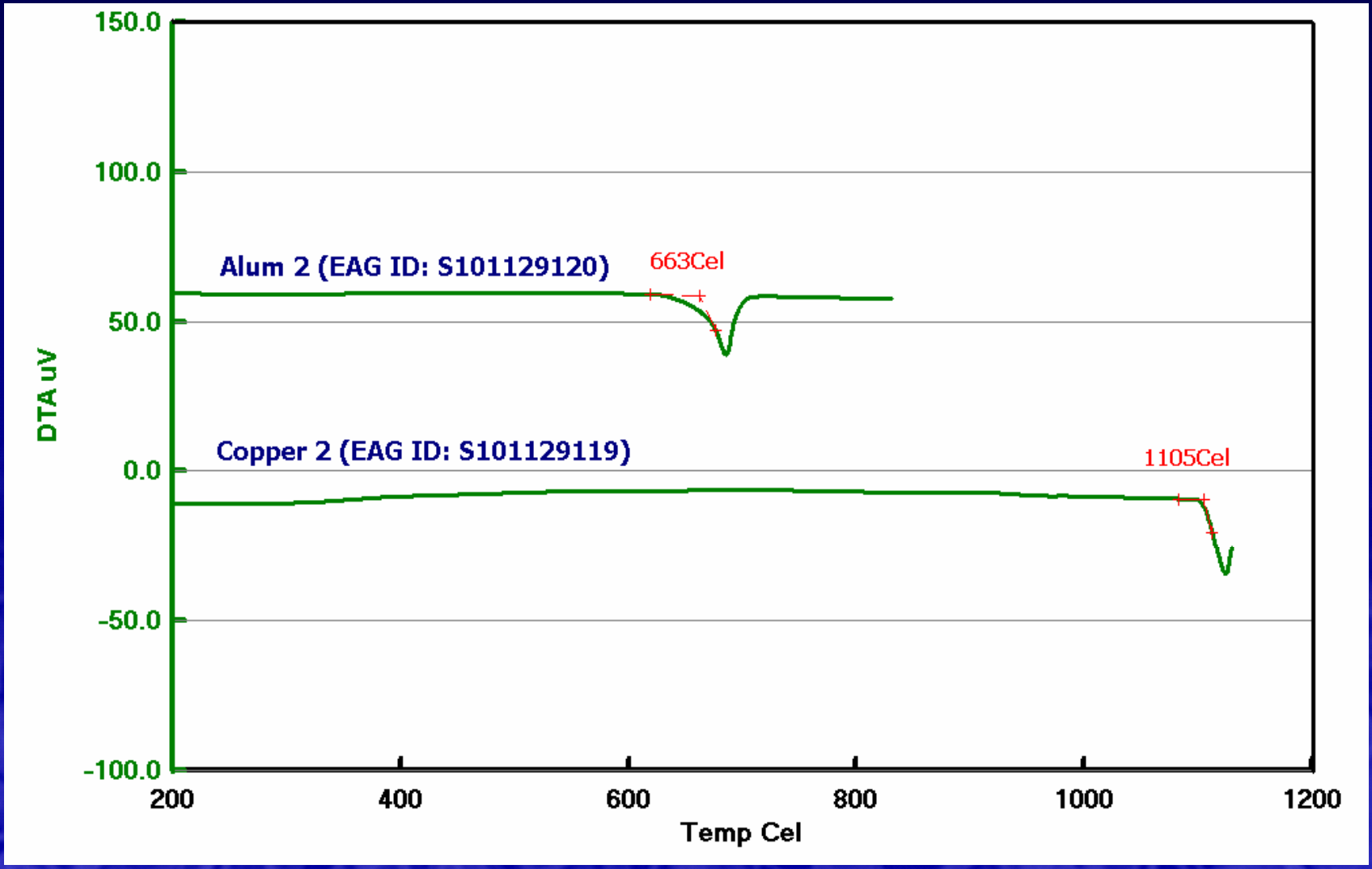
GDMS

"These are indeed very interesting samples. It is evident that both of these samples are sputtering fairly uniform[l]y under normal glow-discharge conditions. However, the texture of the bottom of the plasma craters is very different as compared to ordinary Al and/or Cu samples." --Karol Putyera, Evans Analytical

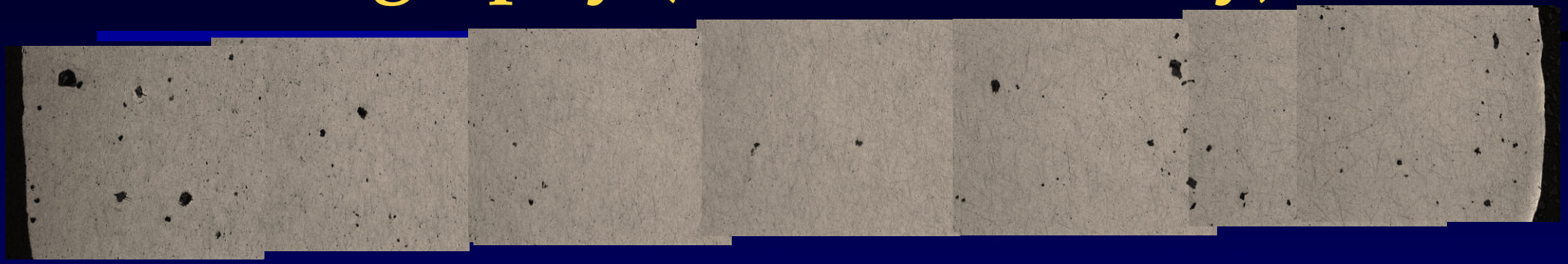


Differential Thermal Analysis

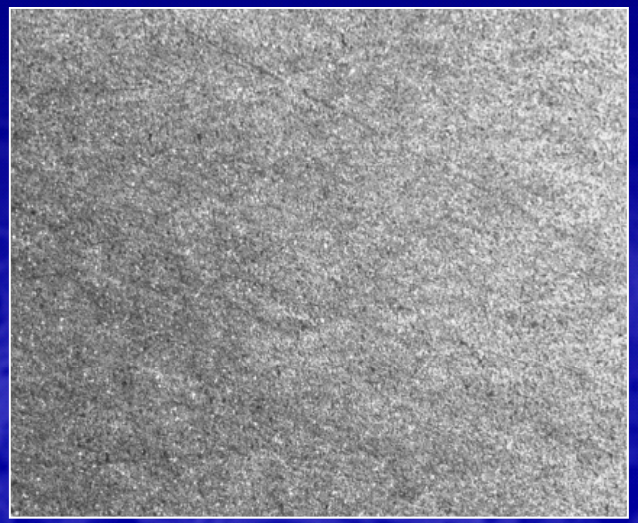
Melting temperature is increased: 663°C vs. 652°C (the liquidus temperature of AA6061).



Metallography (Naval Academy)

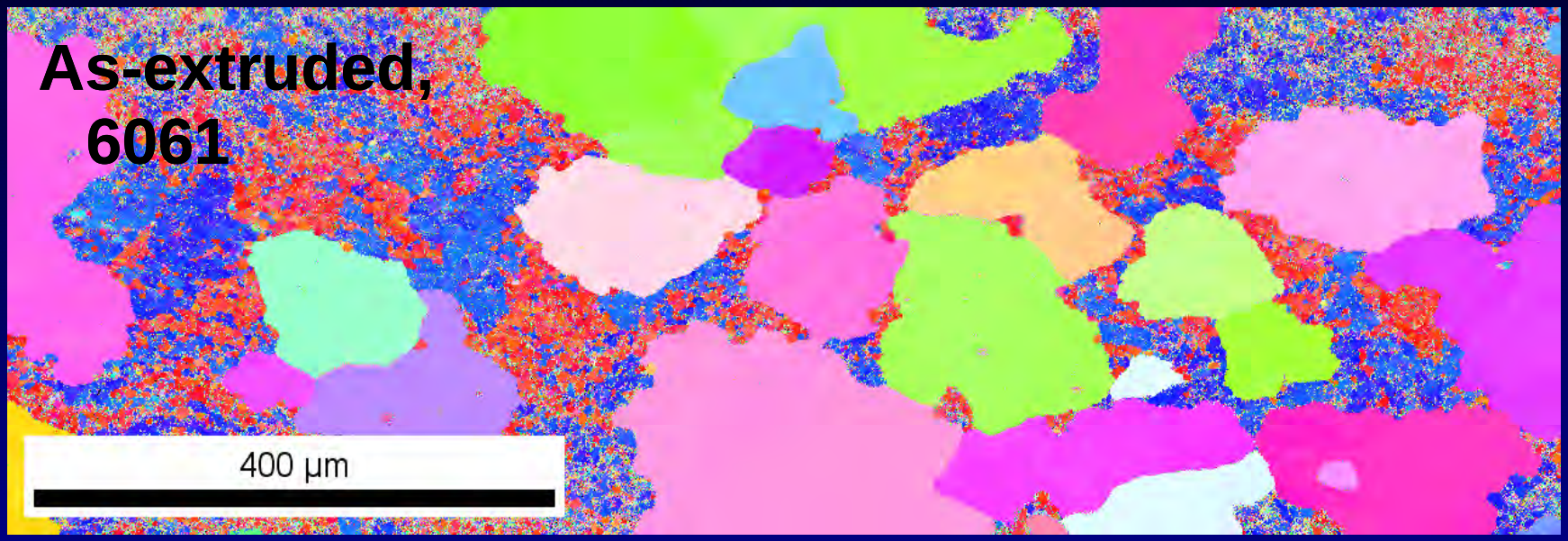


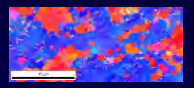
•Composite cross section of H49 covetic aluminum specimen from left to right side
•Specimen mounted and polished using 3 μm diamond grit
• 50X magnification.
• Carbon inclusions present in greater fractions around perimeter of stock material, with larger “spots” towards outer edges.

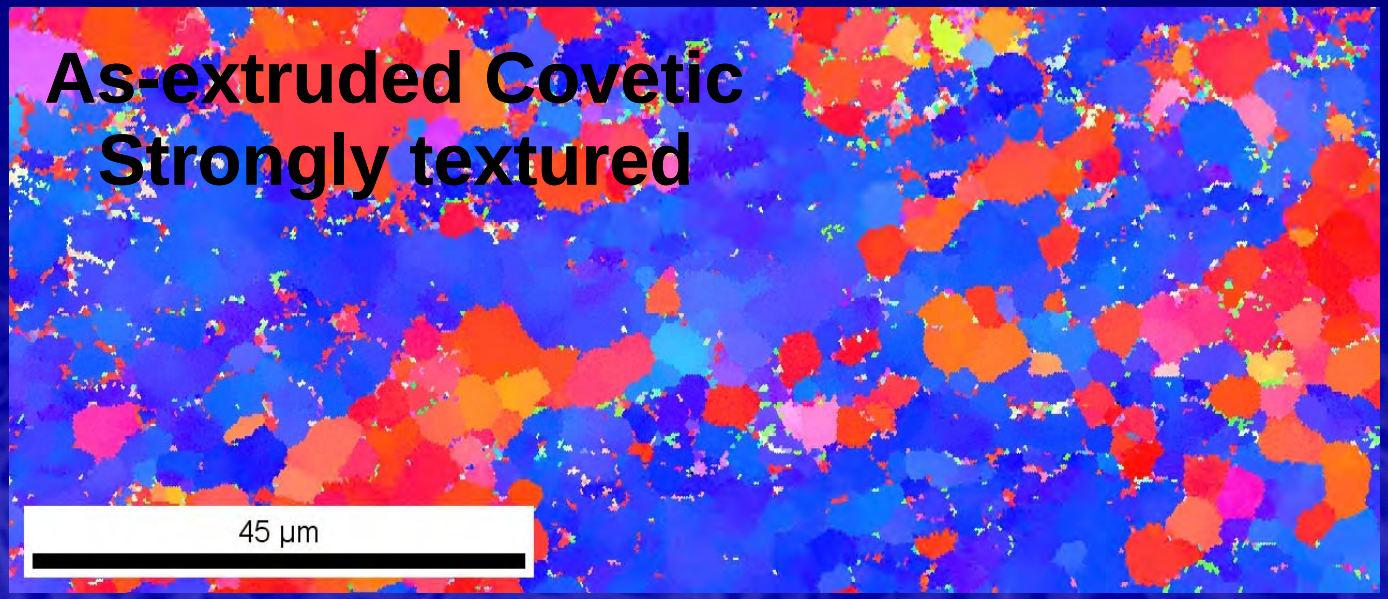


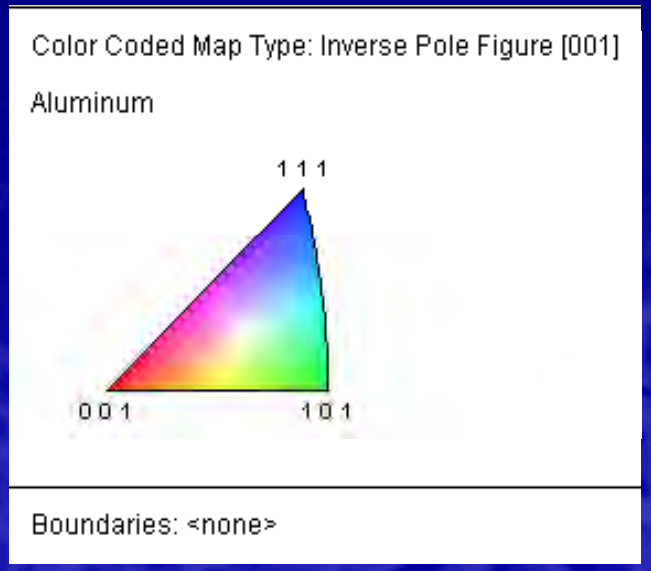
•Typical cross section of comparison 6061
•50X magnification
•Almost no inclusions noted

Electron Backscatter Diffraction (Wolk): Covetic has much finer grain size









Density of 6061
Naval Academy, CDR Lloyd Brown

As-extruded material

- Density = 2.647 g/cm^3 Covetic 6061
  2.683 g/cm^3 Normal 6061
- Assuming ρ_C = 2.25 g/cm^3 and ρ_{6061} = 2.683 g/cm^3, carbon content = 7 wt%
- But we want to re-measure with ultrapyncometer
  - Should only be 3% C
  - Some error is suspected due to surface condition

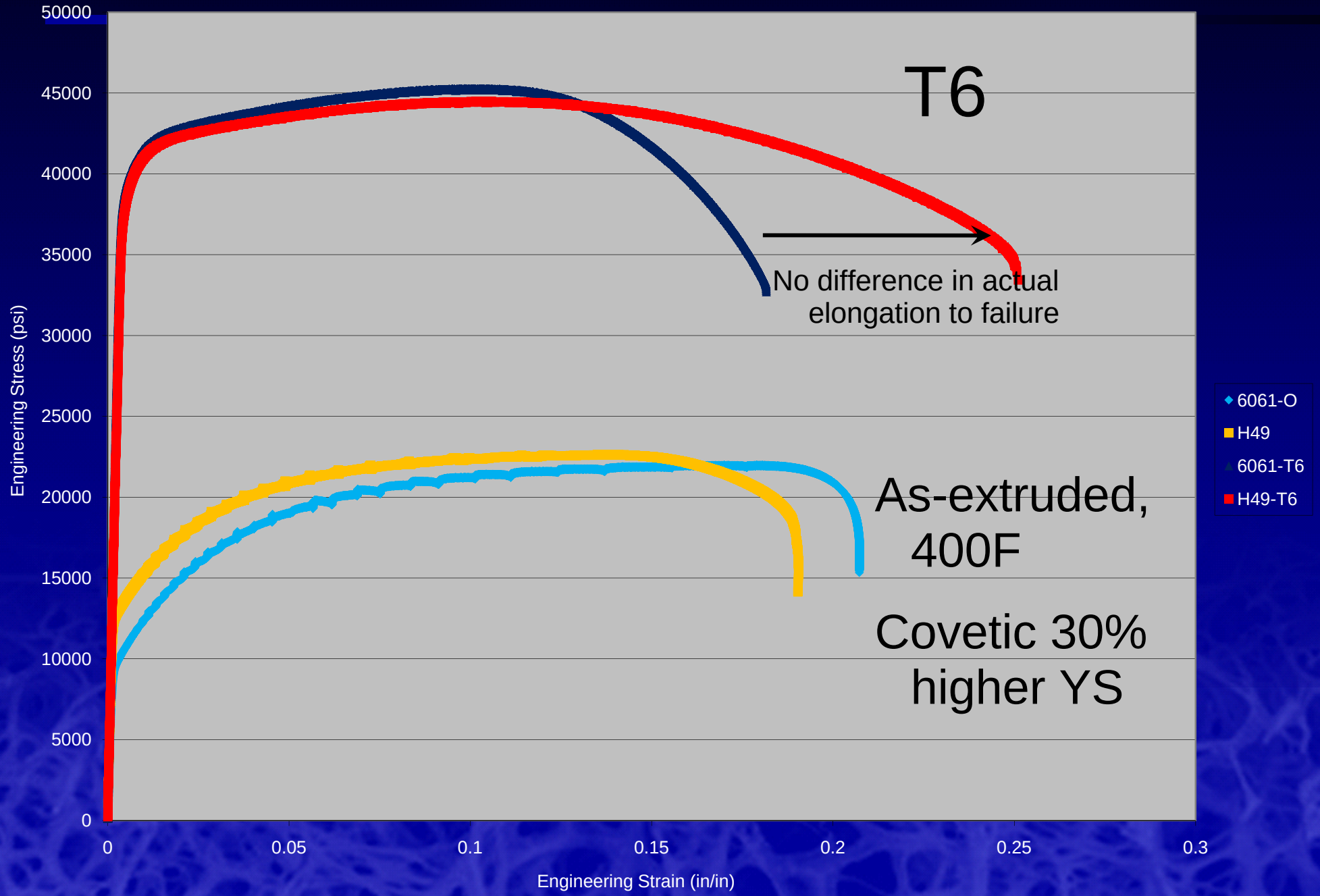
Electrical Conductivity Naval Academy

Covetic 47.81% IACS

6061 47.37% IACS

Covetic: 1% Greater electrical conductivity at room temperature

Tensile Curves: No difference in T6 condition



As-Extruded Hardness (CDR Brown)

- Asymmetric distribution for hardness across center for both specimens, not attributable to pores or inclusions.
- Average covetic hardness = HV 47.6
- Average 6061 hardness = HV 38.7

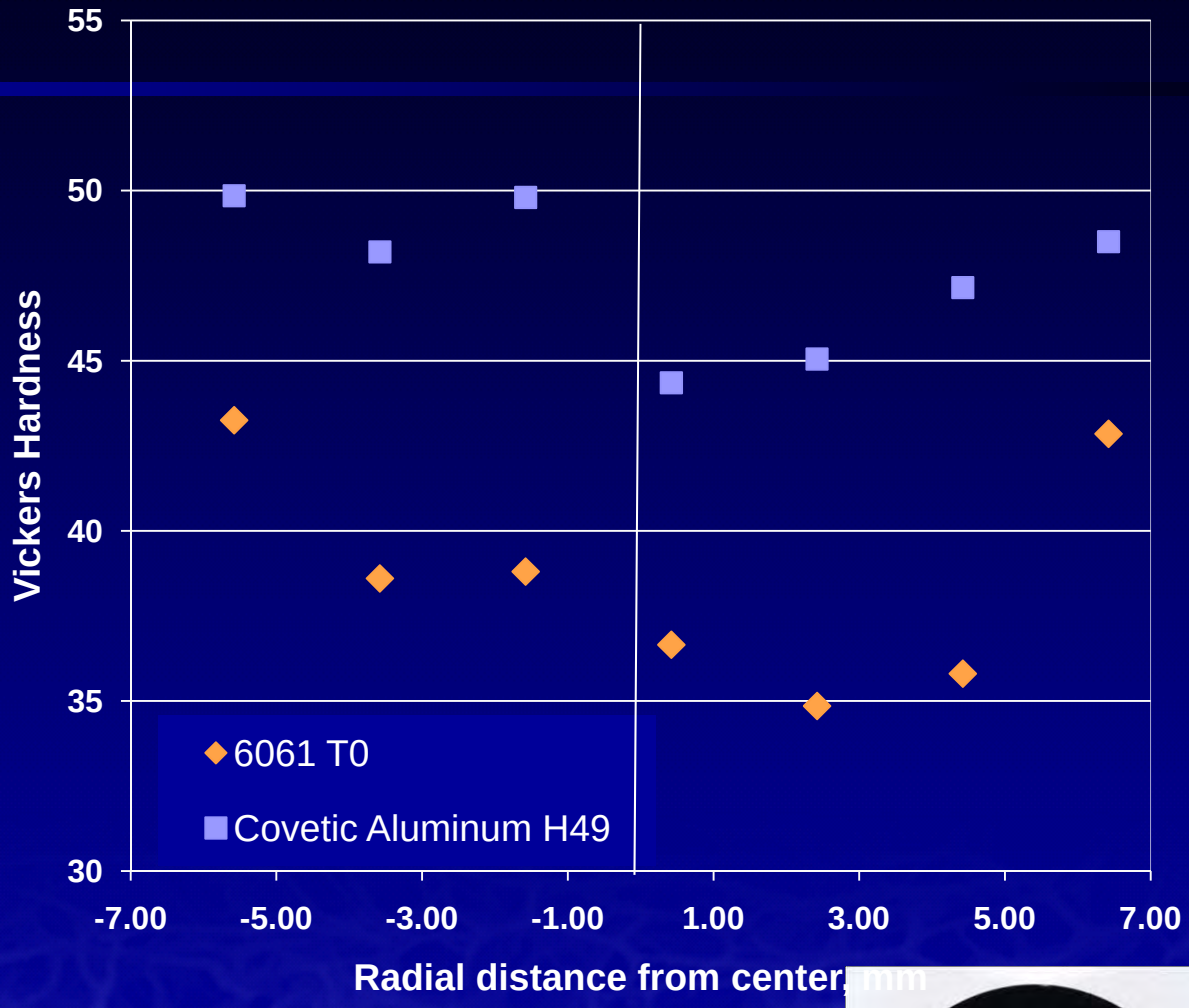
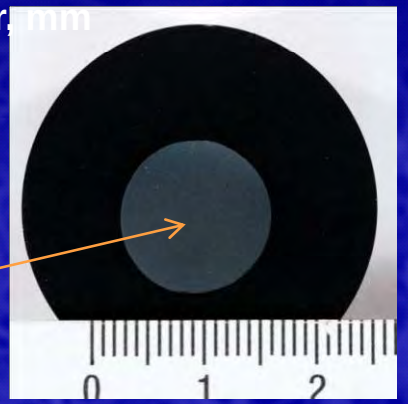
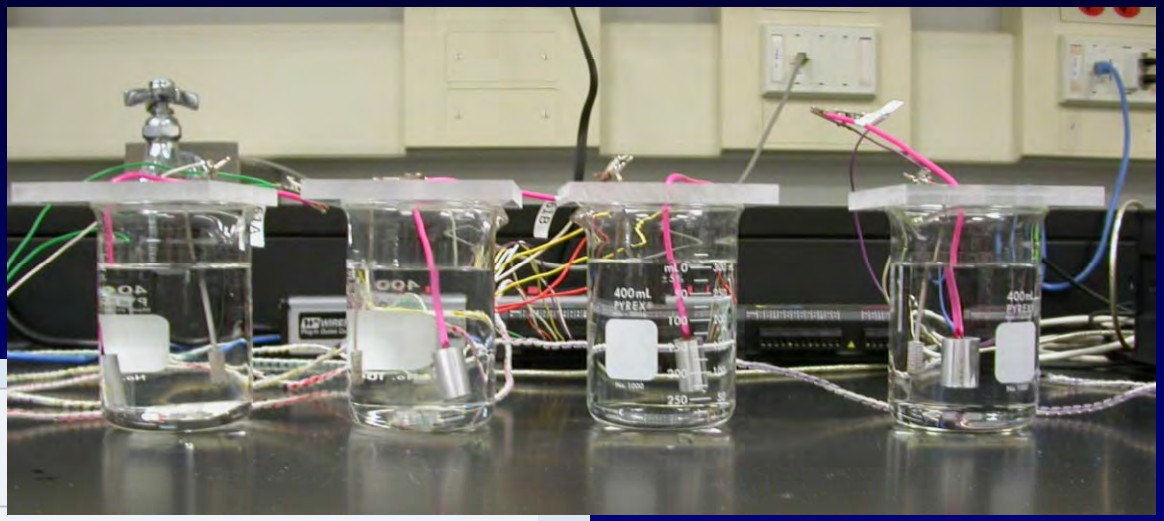
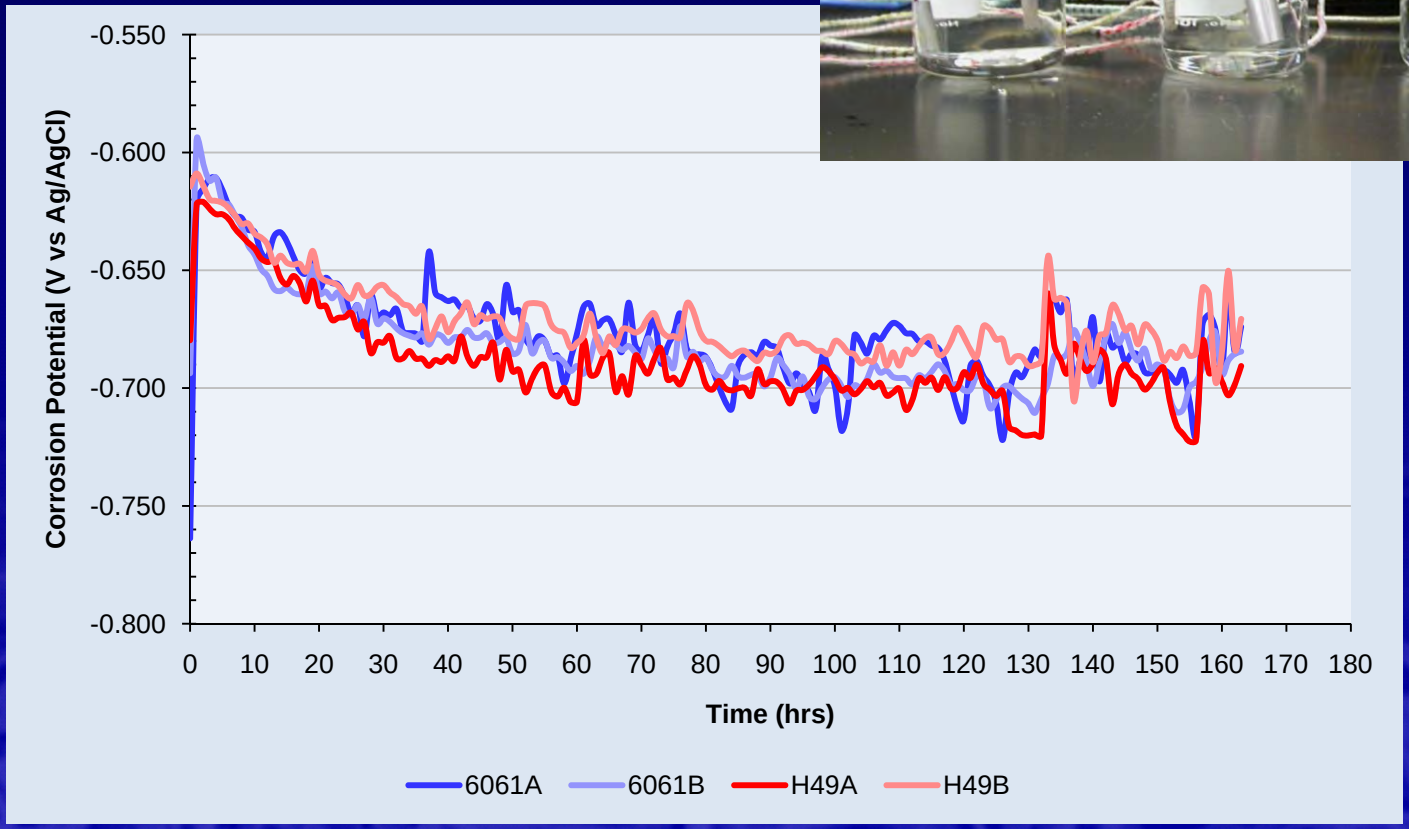


Image of H49 mounted and polished. Hardness values for both H49 and 6061 specimens measured from center.

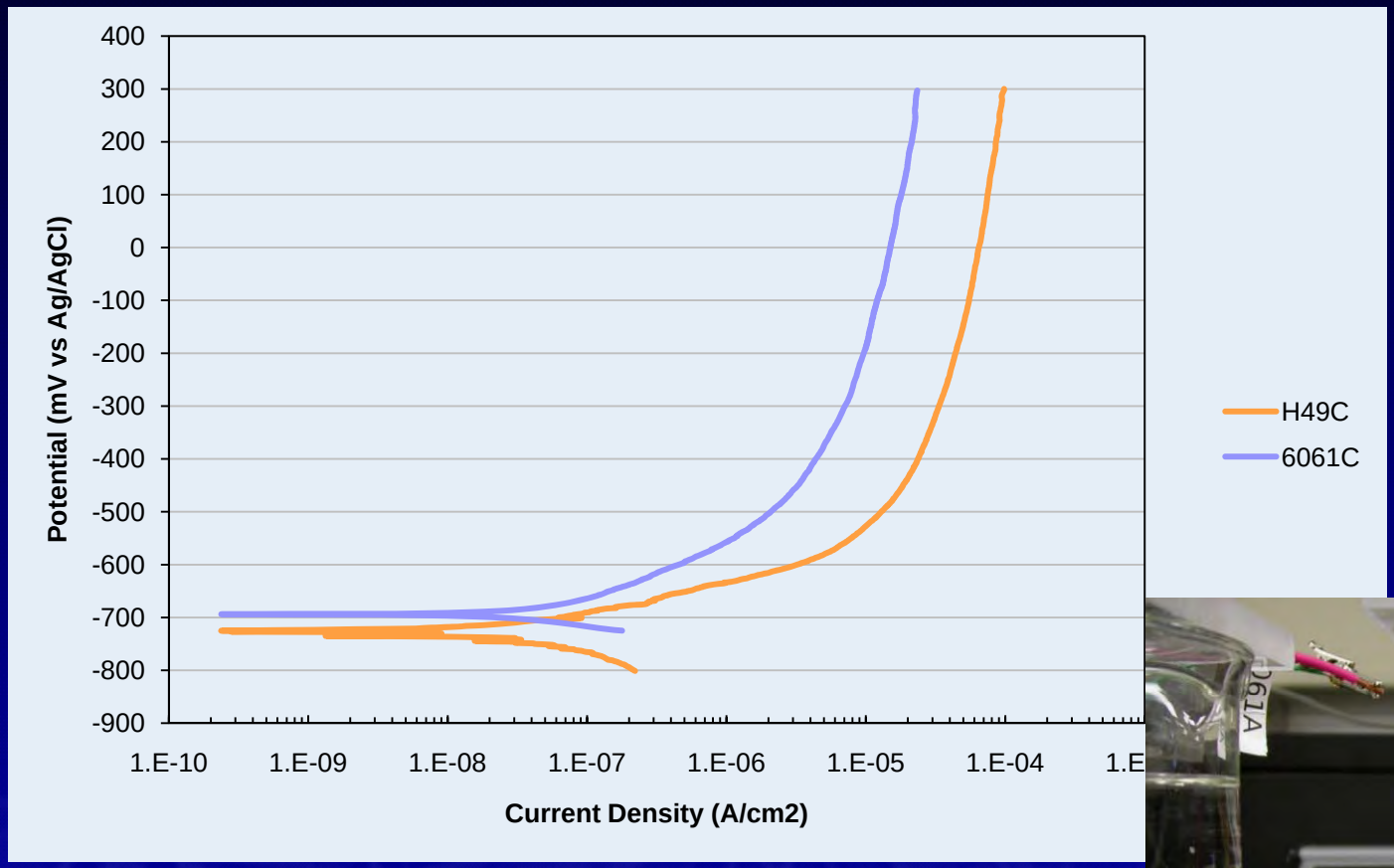


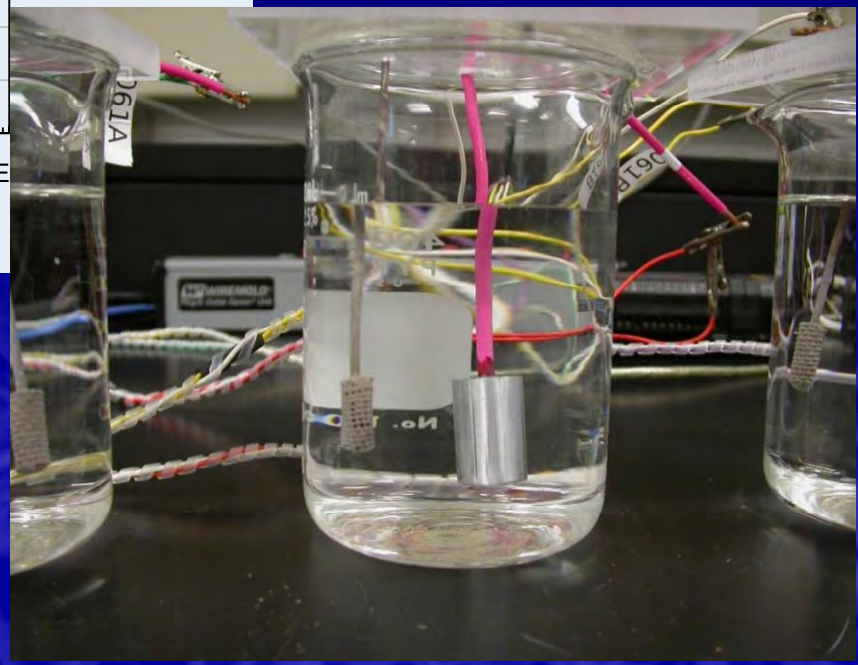
Open Circuit Potential (Seawater): No difference



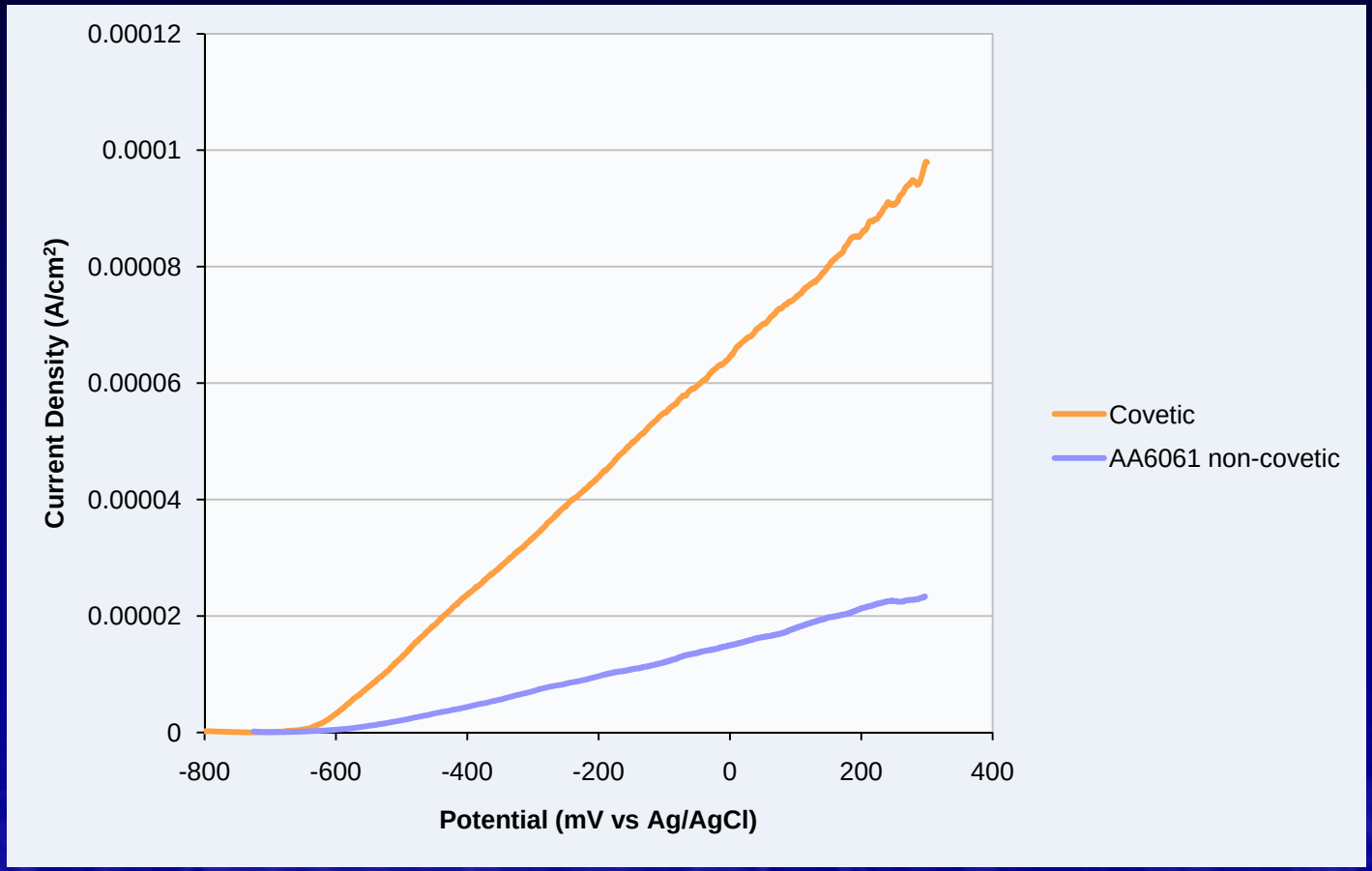


Anodic Polarization in Seawater





Anodic Polarization in Seawater



Factor of 5 increase in current in artificial seawater: Greater conductivity through the passive film?

Thermal conductivity

- Covetic copper: 1.6X thermal conductivity of Electrolytic Tough Pitch Cu (in cold work direction)
  - Reduced conductivity in orthogonal direction, by 75%
- Normal 90Cu-10Ni: 71 W/m-K
  Covetic 90Cu-10Ni: 290 – 460 W/m-K
- Thermal conductivity of aluminum also expected to be much higher (but no data)

Summary

- Nanoscale carbon is not detectable by LECO or GDMS
- Nanoscale carbon raises the melting point of both Al and Cu

Covetic 6061

- Contains several weight % nano-carbon
- Has higher warm-worked strength than normal 6061
- Has significantly finer grainer size and is more strongly textured
- Has 1% higher electrical conductivity
- Probably has much higher thermal conductivity
- May have improved ballistic performance

Note: Annealing and solution treatment wipes out strength differences between cold/warm-worked covetic vs. normal, but covetic material has a slower annealing response so should maintain strength better in moderately elevated temperature applications